Siemens Solar Industries

Technology Partner

Background

Siemens Solar Industries (SSI, a limited partnership registered in Delaware and headquartered in Camarillo, California) purchased ARCO Solar, the world's largest manufacturer of photovoltaics (PV) in 1990. The U.S. Department of Energy/ National Renewable Energy Laboratory (DOE/ NREL) Thin-Film Program has supported pioneering work in $CuInSe_2$ (CIS) technology at ARCO-Siemens since 1987. At that time, ARCO Solar won a 3-year, 50% cost-shared award for about $1.6 million per year from NREL (with an additional $1.6 million corporate cost share). During that contract, ARCO made major progress in (1) developing a new, simplified method of depositing thin-film materials, (2) fabricating PV cells of greater than 14% efficiency (active-area basis, then the world record), (3) fabricating its first interconnected submodules, reaching a world record of 11% at 0.09 m^2 in 1988, (4) developing an early version of the equipment for scaling up its process to larger sizes (about 0.38 m^2), and (5) making its first large modules.

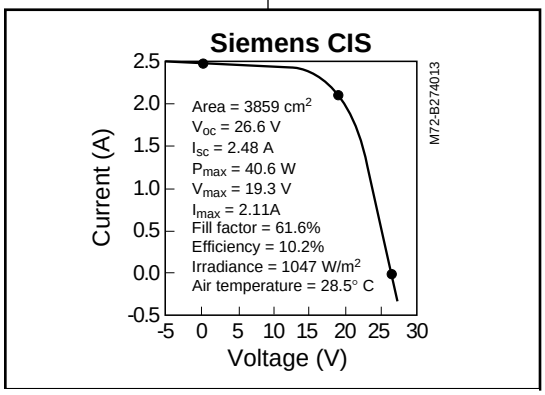

Figure 1. In order for PV modules to meet product requirements, they must be scaled up in size to ~0.4 m^2. This size module has wide application and is called a "power module." In 1994, SSI was able to fabricate the first thin-film power module to exceed 10% efficiency. This module remains the highest efficiency thin-film power module in the world.

When ARCO Solar made the world's first thin-film submodule (~0.09 m^2) to exceed 10% conversion efficiency in 1988, it was the first serious indication that thin films could produce electricity at performance levels similar to existing wafer-based silicon PV technologies. It also established the potential of thin films to reach the performance needed to reduce costs to less than $1/peak watt ($W_p$)—compared to today's PV module costs of about $3–$4/W_p.

In 1991, SSI began a new 3-year subcontract at about $700,000 per year (plus equivalent cost share). During the period of that subcontract, SSI fabricated a 0.37-m^2 power module (Figure 1) with world record efficiencies (greater than 10%) and test cells with reported active-area efficiencies greater than 16% (near state of the art).

In 1994, SSI won a cost-shared research contract as a Technology Partner within the Thin-Film Partnership Program. SSI received 3 years of funding at about the $1 million per-year level from DOE/NREL, while contributing the same amount via cost sharing. As part of the Partnership, they are participating with other awardees on the CIS National Research and Development (R&D) team. SSI's progress to precommercial technological success (through scale-up to pilot production) has been achieved with the support of the DOE/NREL Thin-Film Program.

NREL's partnership with SSI is more the rule than the exception in terms of NREL's DOE-sponsored PV Program. Through NREL-managed, competitive, cost-shared R&D subcontracts, NREL has "partnered" with the leaders in PV on the assumption that they will lead the way toward true commercial success. At the same time, NREL's in-house researchers have played a facilitating role, supporting near-term corporate progress while identifying and addressing key longer-term research problems.

Technical Highlights

In order to make a new, viable PV product, SSI has had to address key technical issues such as (1) improved PV cell efficiencies, (2) high-yield film fabrication and processing techniques, (3) process quality control, and (4) outdoor reliability. These issues manifest themselves in terms of cell and module efficiencies, module scale-up (size and efficiency), prototype yields in pilot production, process rates and materials utilization, and outdoor and accelerated test results on modules. Figure 2 shows a very long-term outdoor test of six ARCO-SSI modules at NREL. They show stable performance for all modules for periods over 8 years. This outdoor performance is a benchmark for all thin films. Figure 3 shows a 1-kilowatt (kW) array of SSI CIS modules now being tested at NREL. Initial stability results are excellent. Figure 4 is a histogram comparing early SSI module manufacturing yields with the improved yields they have achieved under the most recent NREL subcontract. The efficiency of SSI's champion submodule has now reached 12.7%. This progress is significant in terms of reaching reasonable manufacturing costs.

As part of their efforts to address key issues, SSI and NREL's in-house researchers have worked together to share NREL's expertise on CIS film fabrication and high-efficiency device design. NREL researchers hold the world record for the most efficient laboratory CIS cell: 17.7% (total area basis, standard conditions) in 1996. NREL has shared this expertise with SSI in order to facilitate its evaluation of different film fabrication techniques. In addition, NREL materials characterization researchers have worked with SSI personnel to fully analyze SSI's film properties, especially the composition of graded layers and the level of potentially harmful impurities.

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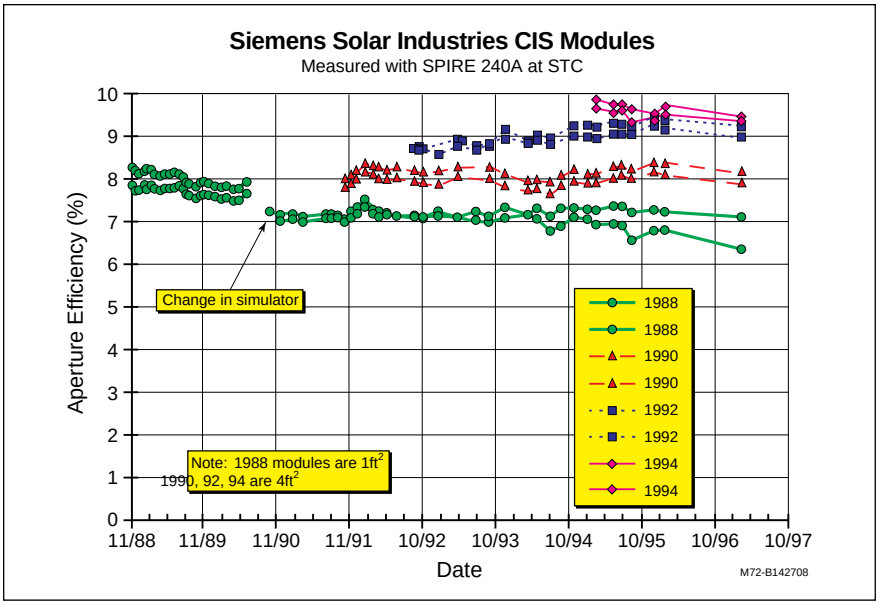

Figure 2. ARCO Solar's (now Siemens Solar Industries) CIS modules are remarkable for their stability over the past 8 years and are the benchmark for all other thin films.

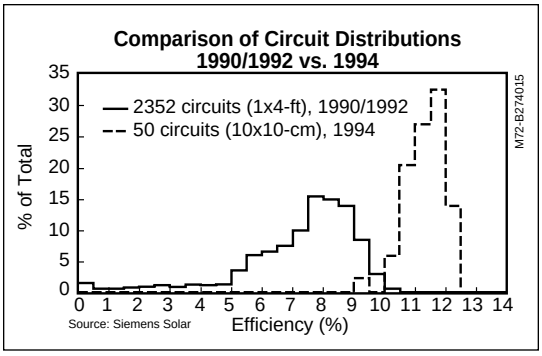

Figure 4. A focus of the NREL subcontract at SSI has been to address key premanufacturing issues such as yield for prototype processes. SSI found that the major barrier to successful manufacturing of CIS was reproducibility. To address this problem, it re-examined all the critical issues implicit in fabricating interconnected modules. The result was a major jump in both efficiency and the tightness with which those efficiencies are produced. This is the key step needed to allow SSI to move toward pilot production of CIS.

Future Plans

Chet Farris, the chief operating officer of SSI, says, "NREL has been outstandingly cooperative in supporting our progress in developing CIS." DOE/NREL and SSI look forward to continued shared efforts to develop the SSI thin-film technology. The Thin-Film Partnership is designed to assist SSI in two important ways: by helping SSI to address key technical problems as it moves through the pilot production phase and by working with SSI (and through the CIS National Team) to maintain a high level of progress toward the development of improved "next generation" products.

Figure 3. For more than 2 years, NREL has been testing the first 1-kW array of CIS modules. The performance of the SSI array has been stable and consistent with the previous data (Figure 2), which were based on individual modules.

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